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Stabilizing Smoked Salmon (*Oncorhynchus gorbuscha*) Tissue after Extraction of Oil

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ABSTRACT: Alaska salmon oils are rich in n-3 polyunsaturated fatty acids and are highly valued by the food and pharmaceutical industries. However, the tissue that remains after oil extraction does not have an established market. Discarded pink salmon (*Oncorhynchus gorbuscha*) tissues were preserved using a combination of smoke-processing and acidification with lactic acid bacteria (LAB). All samples were analyzed for moisture, protein, ash, and lipid contents. Bacterial cell counts, pH, and lactic acid concentrations were recorded as a measure of LAB viability. Neither raw nor smoked salmon were free from spoilage during 60 d of storage. Only fermented samples successfully stabilized below pH 4.7, while retaining lactic acid concentrations over 15 g/L during storage. When smoked, fermented salmon head tissues were dried, the pH of the resulting high-protein "cracker" was significantly lower than when crackers were prepared only from the smoked (but not fermented) salmon material. Both cracker varieties retained valuable polyunsaturated fatty acids. This research suggests that salmon-head tissues discarded after oil extraction represent a good source of protein and high-value fatty acids in a shelf-stable form.

Practical Application: Alaska salmon oils are rich in n-3 polyunsaturated fatty acids and are highly valued by the food and pharmaceutical industries. However, the tissue that remains after oil extraction does not have an established market. Material produced from salmon tissue discarded after oil extraction may represent a valuable resource for preparing high-protein crackers and other fish-based food products. In addition to providing a unique smoke-flavoring, the smoked, fermented fish material may also impart antioxidant factors thereby extending the shelf life of the product.

Keywords: Alaska, fermentation, salmon, smoke, stabilization

Introduction

Over one-half the total fish harvested in the U.S. is from Alaska, and about 9% of the catch is salmon (Crapo and Bechtel 2003). Wild-caught Alaskan salmon contain valuable oils with high concentrations of long-chain n-3 polyunsaturated fatty acids (PUFAs). These oils are sufficiently valuable and are being increasingly extracted from fish processing byproducts. However, high-protein fish tissues remaining after oil extraction are often discarded unless a convenient method of stabilization, such as fish meal production is available. Stabilizing the de-oiled salmon tissues and incorporating them into foods may present challenges if residual oils remain since PUFAs in the tissues can decrease the oxidative stability of the final product (Augustin and Sanguansri 2003).

Smoke-processing has historically been used as a method for preserving food. Wood smoke protects foods from oxidation by imparting chemicals such as phenols, organic acids, alcohols, carbonyls, hydrocarbons, and nitrogen compounds such as nitrous oxide (Pearson and Gillett 1996; Schwanke and others 1996). High levels of phenolic compounds in smoked Nile perch were associated with a lesser degree of lipid oxidation in the tissues during storage than samples containing fewer phenolics (Marc and others 1998). However, sometimes there are health risks associated with smoked food products (Gomaa and others 1993).

Fermentation with lactic acid bacteria (LAB) is also a well-known method for preserving food. LAB lower the pH of foods through the production of organic acids, mainly lactic acid, which inhibit many pathogenic and spoilage organisms (Vandenbergh 1993). Lactic acid in its undissociated state can collapse the electrochemical proton gradient across the membranes of susceptible bacteria and has been found effective against many microorganisms including *Listeria monocytogenes* in salmon (Tomé and others 2006). Additional protection is offered by some strains of LAB that produce bacteriocins active against spoilage bacteria (Marrug 1991). Successful fermentations of salmon using *Lactobacillus* species as starter cultures were found to extend the shelf life while producing a desirable flavor (Morzel and others 2000). For salmon, a pH of 5.1 was achieved after 21 d of fermentation (Morzel and others 1997), whereas a pH of 4.1 was obtained when yellowfin tuna was fermented using LAB (Glatman and others 2000).

A combination of fermentation and smoke-processing was used to prepare a fish product from Atlantic salmon (*Salmo salar*) and saithe (*Pollachius virens*) using *Lactobacillus sakei* as a starter culture (Nordvi and others 2007). This stable, semi-moist product retained its high PUFA level and other nutritional values. However, there is always a concern that biogenic amines may be formed if bacteria capable of decarboxylating the amines are present in the fish. Addition of LAB starter cultures were shown to inhibit growth of proteolytic and decarboxylating microorganisms. Maijala and Eerola (1993) tested 42 homofermentative strains of LAB for histamine production and reported no biogenic amines in starter cultures commonly used to ferment dry sausages.

Recently smoke-processing has been shown to inhibit oxidation of PUFA-rich fatty acids in salmon (Bower and others 2009). The objective of this study was to compare compositional and microbiological characteristics of smoke-processed pink salmon (*Oncorhynchus gorbuscha*) head tissues remaining after oil extraction and to further stabilize this material through LAB fermentation.

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Materials and Methods

Salmon heads

Pink salmon (*Oncorhynchus gorbuscha*) heads ($n = 108$, ranging from 113 to 608 g) were collected from a commercial processor located in the city of Kodiak (Kodiak Island, Alaska) and stored at −20 °C until shipped to Fairbanks for processing. Approximately 72 salmon heads were randomly selected and placed in a Bradley Smoker (Bradley Technologies Canada Inc., Richmond, British Columbia, Canada), and smoked (95 °C, 5 h) using hickory bisquettes. Raw and smoked salmon heads were processed separately using a Tor Rey F12-FS meat grinder (Tor Rey USA, Inc., Houston, Tex., U.S.A.) with a 0.32 cm (1/8 inch) plate. Ground salmon heads were placed into 250 mL Nalgene centrifuge bottles for oil extraction (16,500 × g; 20 min; 4 °C) using a Beckman J2-HS centrifuge (Beckman Coulter, Inc., Fullerton, Calif., U.S.A.) equipped with a JA-14 rotor.

Lactic acid bacteria

The LAB cocktail consisted of 3 strains (*Lactobacillus curvatus* NRRL B-4562, *Lactococcus lactis* NRRL B-1821, and *Pediococcus pentosaceus* NRRL B-14009), since different LAB strains impart different chemical properties and inhibitory characteristics (Gelman and others 2001). Homofermentative strains, producing only lactic acid from glucose, were chosen to maximize lactic acid production as heterofermentative LAB strains do not improve stabilized tissue quality (Cai and others 1998). All strains were tolerant to sodium chloride at 2.5% and capable of fermenting sucrose. All LAB were obtained from A.P. Rooney of the USDA ARS Microbial Genomics and Bioprocessing Research Unit in Peoria, Ill.

Preparation of treatment groups

After removal of oil, material from the whole ground heads was divided into 3 treatment groups. The first treatment group contained raw salmon with 2.5% (w/w) sodium chloride (NaCl) to inhibit spoilage bacteria (Ahmed and others 1996). The second treatment group contained only smoked salmon tissue. The third treatment group consisted of smoked salmon tissue, plus a cocktail of lactic acid bacteria (LAB) inoculated at a concentration of 10^7 CFU/g, and 5% sucrose to promote fermentation of the smoked tissue. The 3 groups were coded as Raw, Smoked, and Smoked-LAB, respectively. Nine glass jars (1 L), each containing 250 g of sample, were set up for each treatment group so that storage experiments could be evaluated in triplicate at 15, 30, and 60 d. Containers were sealed to promote a reduced-oxygen environment, thereby inhibiting the growth of mold and supporting the fermentative processes of LAB to maximize lactic acid production. The temperature of incubation was 20 °C. All samples were analyzed for composition (moisture, lipid, protein, and ash), pH, lactic acid content, and bacterial counts (total CFU/g, lactic acid bacteria, and coliforms).

Bacterial enumeration

Total bacterial cell counts were carried out by plating serial dilutions from Butterfield's buffer (Hardy Diagnostics, Santa Maria, Calif., U.S.A.) onto BHI agar (Oxoid, Ltd., Basingstoke, Hampshire, England). Coliforms were enumerated on MacConkey agar (Oxoid), and presumptive lactic acid bacteria were counted on MRS agar (Oxoid). BHI plates were incubated up to 1 week to check for mold.

Compositional analysis

Samples from each treatment group (Raw, Smoked, and Smoked-LAB) were separately weighed out in triplicate and analyzed in duplicate for each of the following 4 tests. Moisture was determined gravimetrically by drying samples for 24 h at 103 °C and measuring water loss to constant weight (method 952.08, AOAC 1990). Protein was measured by drying samples and analyzing for nitrogen content on an Elementar Rapid NIII analyzer (Elemantar Americas, Inc., Mt. Laurel, N.J., U.S.A.) using WINRAPID™ software, which measures nitrogen values and multiplies by a conversion factor of 6.25 (based on the protein to nitrogen ratio of bovine serum albumin) to calculate protein values. Lipids were determined by processing dried samples on a Soxtec Model 2043 (Foss, Eden Prairie, Minn., U.S.A.) using a dichloromethane extraction solvent (12 mL/g), after which lipid-rich solutions were evaporated to dryness to remove solvent and then weighed (method 991.36, AOAC 1990). Ash content was determined by placing samples into a muffle furnace at 550 °C for 24 h and then weighing the remaining material (method 938.08, AOAC 1990).

Lactic acid assay

This assay was performed according to the procedure of Taylor (1996) where hot sulfuric acid is used to cleave acetaldehyde from lactic acid molecules. The acetaldehyde reacts with copper and p-phenylphenol to produce a chromogen (570 nm). Samples were diluted to fall within the standard graph range of 10-2 to 10-3 g/L. The assay was linear to a sensitivity of 0.4 g/L.

Preparation of crackers

Smoked and Smoked-LAB samples were rolled flat and dried (60 °C, 48-144 h) in a Thelco Laboratory Oven (Precision Co., Winchester, VA). For oil oxidation analyses, crackers (about 5 g dry material) were combined with about 20 g diatomaceous earth and transferred to a 33-mL stainless steel extraction cell, each fitted with 3 cellulose filters and a layer of sand. Oil extraction was carried out using a Dionex ASE 200 accelerated solvent extractor (Dionex Inc., Sunnyvale, Calif., U.S.A.) operated at 50 °C and 1500 psi. Samples were subjected to 2 extraction cycles consisting of a pre-heat, heat, and static period of 5 min each. Nitrogen was used to purge and pressurize the extraction cells. Three replicates of each sample treatment were extracted. All extracts were then concentrated under nitrogen to about 1 mL using a TurboVap LV (Caliper Life Sciences, Hopkinton, Mass., U.S.A.) solvent evaporator and transferred to amber bottles from which the remaining solvent was evaporated. Lipids were then flushed with nitrogen and stored at -80 °C until further analysis.

Preparation and analysis of fatty acid methyl esters

Methyl esters were prepared according to the procedure of Maxwell and Marmer (1983) to quantify PUFA content in the oils of all cracker samples. An internal standard (23:0) was used. Fatty acid methyl esters were separated and quantified as described by Bechtel and Oliveira (2006). Briefly, an Agilent Technologies (Wilmington, Del., U.S.A.) model 6850 gas chromatograph (GC) equipped with a flame ionization detector (FID) and a DB-23 (60 m × 0.25 mm id., 0.25 μm film) capillary column (Agilent Technologies) was used for separation and quantification of fatty acid methyl esters. Hydrogen was used as the carrier gas at a constant flow rate of 1 mL/min. Detector and injector were held at a constant temperature of 275 °C, and the split ratio was 25:1. The oven programming was 140 to 200 °C at a rate of 2 °C/min, 200 to 220 °C at a rate of 0.5 °C/min, and 220 to 240 °C at a rate of 10 °C/min for a total run time of about 62 min. An autosampler performed the injections of standards and samples at a constant volume of 1 μL. Data were collected and analyzed using the GC ChemStation program (Rev.A.08.03 [847]; Agilent Technologies, 1990–2000). All standards used in the identification of peaks were purchased from Supelco

(Bellefonte, Pa., U.S.A.). The standards used were: SupelcoR® 189-19, bacterial acid methyl esters mix, marine oil nr 1, and marine oil nr 3.

Thiobarbituric acid-reactive substances (TBARS)

The TBARS oxidation assay was performed on all crackers and also on the oils extracted from the crackers. For oil samples, TBARS were determined in triplicate according to Siu and Draper (1978) with slight modifications by dissolving 50 mg oil in 3.5 mL cyclohexane and 4.5 mL of 7.5% trichloroacetic acid (TCA) containing 0.34% thiobarbituric acid (TBA). The TCA minimizes interfering solubles by acid-precipitating the lipoprotein fractions. Samples were mixed for 5 min (to allow the secondary lipid oxidation products from the oil to dissolve into the polar layer), and then centrifuged for 15 min at 1555 × g. The aqueous TCA–TBA phase was separated from the nonpolar solvent and incubated at 100 °C for 10 min to allow formation of a chromogen, which was detected at 532 nm using a SpectroMax Plus microplate spectrophotometer (Molecular Devices, Union City, Calif., U.S.A.). The intensity of color correlated with the quantity of TBARS (principally MDA) in the oxidized oil, and was reported as milligrams per kilogram oil using malonaldehyde-bis as the standard. Although the smoked-oil samples in this study acquired progressively darker colors with increased smoking times and temperatures, full-spectrum absorbance scans revealed no interfering compounds at 532 nm. Tissue samples were analyzed similar to the procedure for oils with the following modifications. Dried crackers (1 g) were mixed with 4 mL water and 10 mL of 10% TCA (containing 1 mM malonaldehyde bis). Samples were homogenized (90 s), then centrifuged (10,000 × g; 15 min). The supernatant (2 mL) and an equal quantity of TBA reagent (containing 3 mg/mL 2-thiobarbituric Acid in water) were heated (20 min; 94 °C), then cooled (10 min; 20 °C) prior to absorbance readings at 532 nm.

Statistical analysis

The effect of treatment was investigated using one-way analysis of variance (ANOVA) conducted with the Statistica v 7.1 software package (Statsoft, Tulsa, Okla., U.S.A.). The ANOVA *P*-value was set to 0.05 and differences between treatments were examined using the post hoc test Tukey's equal N honestly significant differences ($P < 0.05$).

Results and Discussion

Composition of smoked salmon

Salmon heads were smoke-processed as a method for reducing the oxidation of valuable marine lipids (Bower and others 2009). The composition of raw and smoked salmon heads are listed in Table 1. Moisture levels in raw salmon did not vary significantly in 60 d. However, smoke-processed salmon varied in moisture content over time depending on whether oil was extracted from the sample or a carbohydrate source was added to support LAB growth.

Lipid levels in smoke-processed salmon (prior to oil extraction) were higher than in raw salmon, likely due to moisture loss. The smoked tissue that remained after oil extraction still contained approximately 50% of its lipid content, resulting in a smoked material rich in marine oils. The percent lipid appeared to change over time, increasing in samples that did not contain LAB and decreasing in those that did. However, when lipids were evaluated on a dry weight basis, the increase (or decrease) observed was found to directly correlate with the change in percent protein within each sample, suggesting that lipid levels generally remained constant over 60 d of storage. High lipid levels (> 4.1%) have been found to present challenges during formulation of food products. Nordvi and others (2007) decreased the oil content in a smoked, fermented fish product to improve its texture while retaining high PUFA levels. Their studies suggest that a de-oiled salmon product might be suitable for incorporation into a sausage-like product.

Protein levels were statistically higher in samples subjected to smoke-processing, likely due to moisture loss, but remained fairly stable over time within treatment groups. A comparison based on percent dry matter revealed a decrease in percent protein, confirming that proteins were being broken down during storage (Bower and Hietala 2008) except in samples that had been inoculated with LAB, which remained constant as bacterial proteins were introduced.

Table 1 — Compositional analyses of raw and smoke-processed (95 °C, 5 h) pink salmon heads at 0, 15, 30, and 60 d. Results are presented as means ± SE.

	Raw salmon (containing oil)	Smoked salmon (containing oil)	Smoked salmon (oil extracted)	Smoked salmon (oil extracted and LAB[A] added)
Moisture (%)				
0	70.5 ± 0.8^{defg}	66.9 ± 0.2^{abc}	65.7 ± 0.9^{ab}	69.2 ± 0.5^{cdef}
15	71.4 ± 0.2^{fg}	nd	68.2 ± 0.2^{bcd}	65.1 ± 0.1^{a}
30	72.1 ± 0.4^{g}	nd	68.7 ± 0.4^{cde}	65.3 ± 0.1^{a}
60	72.1 ± 1.3^{g}	nd	71.2 ± 0.4^{efg}	67.3 ± 0.4^{abc}
Lipid (%)				
0	8.7 ± 0.4^{e}	10.8 ± 0.1^{h}	5.2 ± 0.2^{abc}	5.3 ± 0.1^{bc}
15	9.3 ± 0.2^{ef}	nd	5.3 ± 0.2^{c}	5.2 ± 0.1^{abc}
30	9.4 ± 0.1^{f}	nd	5.6 ± 0.2^{cd}	4.8 ± 0.2^{ab}
60	10.2 ± 0.3^{g}	nd	6.0 ± 0.0^{d}	4.6 ± 0.2^{a}
Protein (%)				
0	13.5 ± 0.3^{a}	18.0 ± 0.2^{b}	21.3 ± 0.5^{e}	17.7 ± 0.3^{b}
15	13.7 ± 0.3^{a}	nd	21.1 ± 0.3^{e}	19.5 ± 0.3^{cd}
30	13.6 ± 0.2^{a}	nd	20.1 ± 0.1^{de}	18.2 ± 0.2^{b}
60	13.3 ± 0.2^{a}	nd	20.5 ± 0.2^{de}	18.4 ± 0.1^{bc}
Ash (%)				
0	6.3 ± 0.5^{de}	3.9 ± 0.1^{ab}	5.4 ± 0.4^{c}	3.7 ± 0.1^{a}
15	5.9 ± 0.2^{cd}	nd	5.4 ± 0.1^{c}	4.4 ± 0.1^{b}
30	6.3 ± 0.2^{de}	nd	5.4 ± 0.1^{c}	4.4 ± 0.1^{b}
60	6.8 ± 0.3^{e}	nd	5.5 ± 0.1^{c}	4.0 ± 0.1^{ab}

Different superscripts identify values that differ significantly ($p < 0.05$) within categories analyzed (moisture, lipid, protein, and ash).
nd = not determined.
[A]LAB = lactic acid bacteria inoculated at 10^7 CFU/g with 5% sucrose.

Ash levels fluctuated little within treatment groups (based on percent dry matter) and were higher in raw samples than smoked samples. The sum of moisture, lipid, protein, and ash values for each sample should total approximately 100%, since carbohydrates are negligible (<0.5%) in fish tissues (Gram and Huss 1996). However, smoked salmon samples inoculated with lactic acid bacteria (LAB) received 5% sucrose to support bacterial growth, resulting in slightly lower totals than uninoculated treatment groups.

Effect of fermentation on tissue pH

After 60 d of storage, smoke-processed tissue retained more acidity (pH 6.3) than raw tissue (pH 6.8), although neither was able to decrease the pH below 5.0, which is critical for reducing spoilage bacteria and stabilizing the high-moisture products (Figure 1). When both raw and smoked samples were acidified with lactic acid through LAB fermentation, lower values (pH ≤4.5) were attained within 24 to 72 h and remained low for storage times up to 60 d. Typically, LAB fermentations are done at 30 °C or above, which encourages bacterial growth and rapidly leads to increased acid production (<pH 4.0). However, in this study all samples were held at room temperature (20 °C), thereby requiring more time for the LAB fermentates to decrease the pH level.

Lactic acid concentrations

Lactic acid levels were measured to confirm the presence of LAB in inoculated samples. Although LAB are generally considered normal flora of fish (Gram and Huss 1996), the concentration of lactic acid in uninoculated controls was less than 1 g/L, suggesting that lactic acid bacteria were not abundant. Raw salmon tissue fermented with LAB displayed an increase in lactic acid levels over 60 d (Figure 2), which was consistent with a decrease in pH (Figure 1) and an increase in LAB cell counts graphed in Figure 3. Lactic acid concentration in smoked salmon increased to 16 g/L after inoculation with LAB and remained at that level throughout 60 d of storage. The concentration of lactic acid is considered a good indicator of fermentation stability of stabilized tissue (Madrid and others 1999).

Bacterial enumeration

Total bacterial counts were compared in raw and smoked salmon, with or without LAB inoculation, during 60 d of storage (Figure 3). Among the 4 sample types, bacterial numbers for raw salmon without LAB continued to increase as spoilage and Gram-negative bacteria grew unchecked. This is supported by the rising pH in these samples (Figure 1) as well as the low levels of lactic acid being generated (Figure 2). Samples that received LAB inoculations also displayed increasing cell counts, although growth was predominantly LAB as demonstrated by decreased pH and high levels of lactic acid (Figure 1 and 2). All growth on MRS agar was classified as presumptive lactic acid bacteria, since MRS is selective for LAB and only similar colony types (color, size, texture) were observed on the plates. Preservation of ground salmon heads through pH reduction using LAB has been previously found to confer antimicrobial activity against Gram-negative bacteria (Bower and Hietala 2008).

Production of salmon crackers

The Smoked and Smoked-LAB salmon material described in Table 1 and Figure 1–3 were dried into crackers and characterized (Table 2). The pH was significantly lower for crackers fermented with LAB due to the presence of lactic acid generated by the bacteria. After compensating for the added sucrose used as a

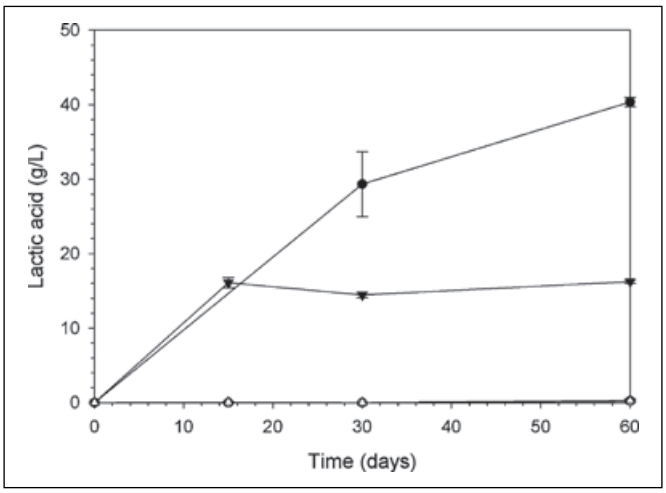

Figure 2—Lactic acid production of ground salmon tissue during 60 d of storage: • raw tissue fermented with lactic acid bacteria; ▼ smoked (95 °C, 5 h) then fermented with lactic acid bacteria; ○ raw tissue; and △ smoked (95 °C, 5 h) tissue. Values represent means ± SE.

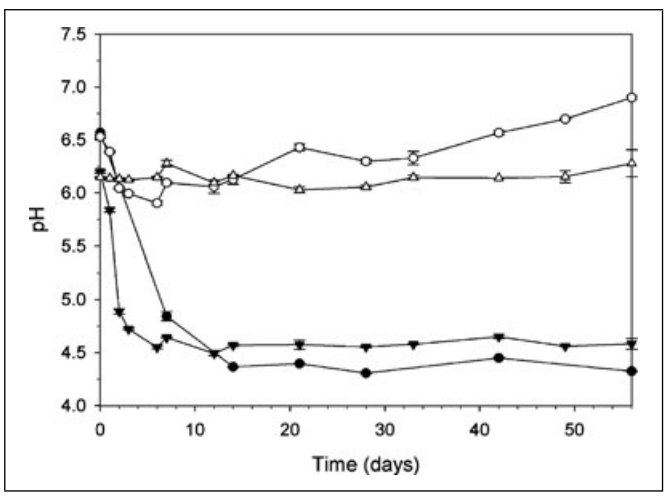

Figure 1—Change in pH of ground salmon head tissue during storage: ○ raw; △ smoked (95 °C, 5 h); ▼ smoked (95 °C, 5 h) then fermented with lactic acid bacteria; and • raw tissue fermented with lactic acid bacteria. Values represent means ± SE.

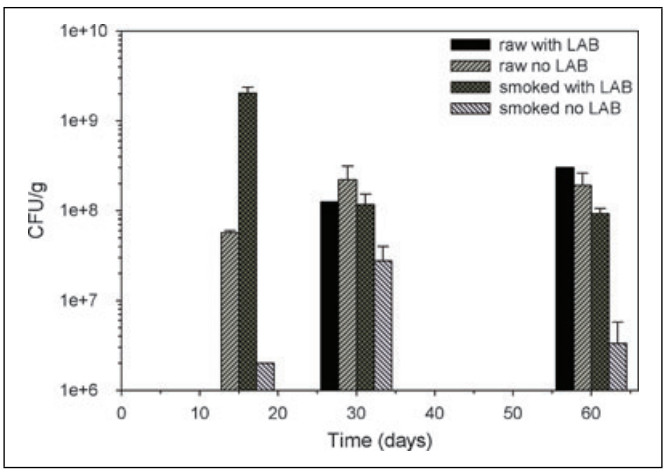

Figure 3—Enumeration of bacteria (CFU/g) in raw or smoked salmon tissue with or without lactic acid bacteria. Initial LAB inoculum was 10^7 CFU/g. Values represent SE (n = 3).

Table 2 — Smoked salmon tissue with or without lactic acid bacteria after processing into dried crackers. (Values represent means ± SE.)

	pH (g/L)	Lactic acid	% Moisture	% Lipid	% Protein	% Ash	TBARS (μg/g)
Smoked tissue	5.8 ± 0.1^{b}	0.0 ± 0.1^{a}	3.6 ± 0.8^{a}	24.7 ± 0.2^{a}	58.9 ± 1.2^{a}	10.2 ± 0.5^{a}	45.3 ± 2.9^{a}
Smoked tissue fermented with LAB	4.2 ± 0.1^{a}	89.1 ± 1.4^{b}	11.5 ± 1.8^{a}	20.3 ± 1.5^{a}	48.3 ± 0.5^{a}	7.2 ± 0.7^{a}	55.8 ± 1.5^{a}

Different superscripts identify values that differ significantly ($P < 0.05$) within each column.

Table 3 — Fatty acids, PUFA levels, and oxidation (as measured by TBARS) for oils extracted from smoked salmon tissues immediately after smoking and oils extracted after the smoked tissues had been treated (with or without lactic acid bacteria) and dried into crackers. Values represent means ± SE.

	Total FA (mg/g)	PUFA (mg/g)	TBARS (μg/g)
Smoked salmon oils	1214 ± 7^{c}	464 ± 3^{c}	11.8 ± 3^{a}
Cracker oils			
Without LAB	$1{,}050 \pm 2^{b}$	387 ± 2^{b}	479 ± 73^{b}
With LAB	$1{,}009 \pm 11^{a}$	358 ± 5^{a}	380 ± 138^{b}

Different superscripts identify values that differ significantly ($P < 0.05$) within each column.

carbohydrate source in the LAB samples, values for moisture, protein, ash, and lipids generally showed little difference between smoked crackers (with or without LAB). Oxidation (as measured by TBARS) was not significantly different among smoked salmon crackers, regardless of whether the samples experienced LAB fermentation or not (Table 2).

Oxidation was also measured for oils extracted from the smoked salmon crackers (Table 3). When compared to the oils extracted from salmon tissues immediately after smoking, the TBARS results were higher for both cracker varieties (prepared with or without LAB), as would be expected since crackers were exposed to an additional heat treatment during the drying process. Fatty acid levels and PUFA quality of the crackers were also compared with oils from the original (non-dried) smoked salmon (Table 3). Oils prior to cracker production retained higher levels of fatty acids and more PUFAs than found in oils after the drying process. However, both smoked cracker varieties (with and without LAB) generally had comparable quantities of fatty acids and PUFAs, suggesting that production of crackers from smoked salmon would represent a good source of essential fatty acids in a shelf-stable form.

Conclusions

A material produced from salmon tissue discarded after oil extraction may represent a valuable resource for preparing high-protein crackers and other fish-based food products. In addition to providing a unique smoke-flavoring, the smoked, fermented fish material may also impart antioxidant factors thereby extending the shelf life of the product. Increased utilization of fish processing discards promises environmental and economic benefits while conserving valuable marine resources. The simplicity of the process and relatively low cost associated with acidification can be an advantage when handling small batches of fish by-products.

Acknowledgments

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